NORTHEAST TEMPERATE NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE NORTHEAST TEMPERATE NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

Literature Cited

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. Environmental Management. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. Atmospheric Environment 31(11):1695-1708.

U.S. National Park Service. 2003. Ozone Sensitive Plant Species on National Park Service and US Fish and Wildlife Service Lands. NPS D1522. Natural Resource Report NPS/NRARD/NRR-2003/01. Air Resources Division. Denver, CO. 21 pp. (Available at www2.nature.nps.gov/ard/pubs/index.htm)

SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE NORTHEAST TEMPERATE NETWORK

Park	Code	State	Risk	O3 Data
Acadia NP	ACAD	ME	moderate	monitored
Boston Harbor Islands NRA	BOHA	MA	moderate	kriged
Marsh-Billings NHP	MABI	VT	low	kriged
Minute Man NHP	MIMA	MA	moderate	kriged
Morristown NHP	MORR	NJ	high	kriged
Roosevelt-Vanderbilt Headquarters	ROVA	NY	high	kriged
Saint-Gaudens NHS	SAGA	NH	low	kriged
Saratoga NHP	SARA	NY	low	kriged
Saugus Iron Works NHS	SAIR	MA	moderate	kriged
Weir Farm NHS	WEFA	CT	high	kriged

A portion of the Appalachian National Scenic Trail passes through the network. A stand-alone assessment of risk has been produced for sites along the Appalachian Trail.

ACADIA NATIONAL PARK (ACAD)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ACAD					
	1995	1996	1997	1998	1999
Sum06	11	4	7	15	12
W126	19.2	10.1	11.2	33.4	28.8
N60	275	123	147	520	378
N80	79	18	24	77	70
N100	13	4	3	21	13

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ACAD					
	1995	1996	1997	1998	1999
Month 1	0.35	-0.18	-1.64	-0.35	-2.83
Month 2	-0.55	5.12	-0.78	5.98	-2.43
Month 3	0.51	-2.49	0.10	-0.83	-1.31

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ACAD					
	1995	1996	1997	1998	1999
April	-1.19	2.69	2.03	-0.92	-4.67
May	0.35	1.09	-0.12	-0.35	-0.38
June	-0.55	-0.18	-1.64	5.98	-2.83
July	0.51	5.12	-0.78	-0.83	-2.43
August	-2.29	-2.49	0.10	0.35	-1.31
September	-1.35	3.00	-0.86	-1.70	4.72
October	0.91	3.61	-2.87	4.36	1.88

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are intermittently satisfied.

- In three years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the other years, the number of hours was significantly lower. In the high ozone years, the levels of exposure could injure vegetation.

- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. In 1998 when ozone concentrations were highest, soil moisture was normal. In the two mid-level exposure years there were three months of mild and moderate drought in 1999 and normal soil moisture in 1995. The two lowest exposure years each had one month of mild or moderate drought. Soil moisture levels associated with the

seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. There was one month of mild drought in 1998, the highest exposure year, and four months of mild to severe drought in 1999, the second highest year. There were three months of mild and moderate drought in 1995, the mid-level exposure year. The lowest and second lowest years, 1996 and 1997 respectively, had one and two months of mild and moderate drought.

The risk of foliar ozone injury to plants at Acadia National Park is moderate. The levels of ozone exposure intermittently create the potential for injury, and exposures to 80 and 100 ppb varies widely among the years. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1998 when ozone levels exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, big-leaf aster, white ash, quaking aspen, black cherry, Allegheny blackberry, and American elder.

BOSTON HARBOR ISLANDS NATIONAL RECREATION AREA (BOHA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BOHA					
	1995	1996	1997	1998	1999
Sum06	16	13	14	16	16
W126	21.7	16.8	19.9	21.9	19.9
N60	333	255	296	337	296
N80	90	38	72	68	74
N100	18	3	12	12	12

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BOHA					
	1995	1996	1997	1998	1999
Month 1	-0.41	-1.56	-1.75	6.79	-3.30
Month 2	-0.70	2.18	-1.04	-0.18	-0.73
Month 3	-2.61	-0.20	0.19	0.48	-1.85

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BOHA					
	1995	1996	1997	1998	1999
April	-1.80	1.88	2.21	0.31	-3.25
May	-0.46	-0.43	-0.23	0.90	0.13
June	-0.41	-1.56	-1.75	6.79	-3.30
July	-0.70	2.18	-1.04	-0.18	-0.73
August	-2.61	-0.20	0.19	0.48	-1.85
September	-0.80	5.52	-2.36	-1.29	2.54
October	1.54	8.00	-2.07	1.39	2.55

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. Most years had 12 or more hours of exposure greater than 100 ppb. These levels of exposure can injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Three years, 1995, 1998 and 1999, had the same highest Sum06 exposure index and experienced one month of moderate drought, normal moisture conditions, and two months of mild and severe drought, respectively. The second lowest and lowest exposure years, 1997 and 1996, had two and one month of mild drought, respectively. There does not appear to be any association between the seasonal W126 accumulative index and soil moisture conditions. The two years with the highest indices, 1995 and 1998, experienced two months of mild and moderate drought and two months of mild drought, respectively. In two years with slightly lower exposures, there were

four months of mild and moderate drought in 1997, and three months of mild and severe drought in 1999. There was one month of mild drought in 1996, the year with the lowest exposure.

The risk of foliar ozone injury at Boston Harbor Islands National Recreation Area is moderate. The thresholds for injury are satisfied for both the Sum06 and W126 exposure indices. The N-values indicate that exposures exceed 80 ppb and 100 ppb, but the numbers of hours at these levels vary among years. Mild to severe drought conditions occur during most years and can significantly reduce the uptake of ozone. It is anticipated that the risk of injury may be greatest in years such as 1998 when ambient levels of ozone are moderately high and soil moisture conditions constrain uptake late in the year.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, American elder, and northern fox grape.

MARSH-BILLINGS NATIONAL HISTORIC PARK (MABI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MABI					
	1995	1996	1997	1998	1999
Sum06	8	5	7	8	9
W126	14.2	11.5	11.7	13.5	16.4
N60	216	145	158	203	245
N80	22	21	20	12	33
N100	1	1	2	0	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MABI					
	1995	1996	1997	1998	1999
Month 1	-3.75	1.22	-0.57	-1.63	-1.63
Month 2	1.84	6.51	3.81	6.56	6.56
Month 3	2.48	-0.80	5.10	4.22	4.22

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MABI					
	1995	1996	1997	1998	1999
April	-0.49	6.44	0.18	-1.30	-1.30
May	-0.28	3.19	2.28	-1.63	-1.63
June	-3.75	1.22	-0.57	6.56	6.56
July	1.84	6.51	3.81	4.22	4.22
August	2.48	-0.80	5.10	2.57	2.57
September	1.53	-0.28	0.61	2.55	2.55
October	5.79	2.29	-0.07	0.26	0.26

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury at a marginal level. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between 90-day Sum06 accumulation period ozone levels and soil moisture are difficult to assess because ozone exposures were low and relatively similar over the five-year period. No relationships were apparent between the Sum06 levels of ozone and soil moisture conditions. In general, soil moisture conditions were favorable for the uptake of ozone with only two months of mild and one of severe drought stress over the five-year period. With the seasonal W126 index there were few months of drought during the five-year period, however there is some indication of an inverse relationship: when ozone is high, soil moisture is low, but the relationship is not consistent. This relationship

reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the three years with the highest ozone, there were two months of mild drought in both 1999 and 1998, and one month of severe drought in 1995. Soil moisture conditions were favorable in the remaining two years with lower levels of ozone.

The risk of foliar ozone injury to plants at Marsh-Billings Historic Park is low. The Sum06 and W126 exposure indices are either marginally attained or not satisfied. The N-values indicate that exposure to ozone greater than 80 ppb is uncommon and exposure to 100 ppb is rare. While soil moisture conditions generally favor the uptake of ozone, periods of drought constrain uptake in higher exposure years and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, big-leaf aster, white ash, American sycamore, quaking aspen, black cherry, Allegheny blackberry, and American elder.

MINUTE-MAN NATIONAL HISTORIC PARK (MIMA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MIMA					
	1995	1996	1997	1998	1999
Sum06	13	10	10	12	12
W126	21.7	16.9	20.2	20.5	20.2
N60	335	255	298	314	305
N80	86	37	67	61	72
N100	15	2	11	12	10

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MIMA					
	1995	1996	1997	1998	1999
Month 1	-1.60	-0.77	-2.49	6.98	-2.92
Month 2	-0.94	3.80	-1.19	-0.15	-0.88
Month 3	-2.24	-1.28	0.06	-1.17	-1.81

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MIMA					
	1995	1996	1997	1998	1999
April	-1.67	3.85	2.01	-0.74	-3.53
May	-0.72	0.43	-0.18	1.10	-0.12
June	-1.60	-0.77	-2.49	6.98	-2.92
July	-0.94	3.80	-1.19	-0.15	-0.88
August	-2.24	-1.28	0.06	-1.17	-1.81
September	-0.60	2.82	-2.11	-1.50	4.74
October	4.43	5.66	-1.62	1.78	1.44

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index marginally exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 threshold was satisfied each year and the W126 criteria in four of the five years.

- The N-values for the site show concentrations frequently exceeded 60 ppb, occasionally exceeded 80 ppb, and exceeded 100 ppb for a significant number of hours in most years. These levels of exposure can injure vegetation.

- Relationships between 90-day Sum06 accumulation period ozone levels and soil moisture are difficult to assess because ozone exposures were relatively similar over the five-year period. Months of mild and moderate drought stress were

distributed over the five years, with three years each having two months of drought and two years each having one month. No relationship was apparent between the Sum06 level of exposure and drought. The relatively uniform levels of ozone also make it difficult to assess relationships between the W126 exposure index and soil moisture, however there appears to be an inverse association: when ozone is high, soil moisture is low, but the relationship is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Exposure indices in 1995, 1997, 1998 and 1999 were high and similar, and each year experienced two to four months of mild to severe drought. The lowest exposure year, 1996, had one month of mild drought.

The risk of foliar ozone injury at Minute-Man National Historic Park is moderate. The thresholds for injury are consistently satisfied for the Sum06 and the W126 indices, and the N-values indicate there are frequent exposures to concentrations of ozone greater than 80 ppb, with a significant number of hours of exposure to 100 ppb in most years. Mild to severe drought conditions reduce the uptake by plants in most years. It is anticipated that the risk of injury may be greatest in years such as 1998 when ambient levels of ozone are high and soil moisture conditions generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, American elder, and northern fox grape.

MORRISTOWN NATIONAL HISTORIC PARK (MORR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MORR					
	1995	1996	1997	1998	1999
Sum06	21	16	20	21	26
W126	33.4	25.9	30.9	36.6	39.2
N60	503	409	465	595	604
N80	179	111	150	178	194
N100	43	15	33	21	57

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MORR					
	1995	1996	1997	1998	1999
Month 1	-1.73	1.31	-1.34	-2.28	-3.26
Month 2	0.13	3.38	1.30	-1.71	-4.17
Month 3	-3.29	-1.64	0.10	-1.98	-0.54

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MORR					
	1995	1996	1997	1998	1999
April	-1.97	1.45	0.00	1.42	-1.63
May	-0.54	-0.53	-0.41	1.87	-0.83
June	-1.73	1.31	-1.34	2.36	-3.26
July	0.13	3.38	1.30	-2.28	-4.17
August	-3.29	-1.64	0.10	-1.71	-0.54
September	-0.07	1.82	-0.71	-1.98	6.12
October	4.17	5.16	-1.16	-1.28	0.56

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. Ozone levels during the Sum06 accumulation periods were relatively similar over the five-years. The year with the highest Sum06 ozone exposure value, 1999, had two months of severe drought. The three years with a slightly lower ozone exposure, 1995, 1997, and 1998, each had one to three months of mild to severe drought, with 1998 being most significantly affected. In the lowest ozone year, 1996, there was one month of mild drought. The W126 index of exposure and soil moisture levels also appear to have an inverse relationship. The two years with the highest exposures, 1999 and 1998, experienced three and four months of mild to severe drought, respectively. In the two intermediate exposure years there were three months of mild and severe drought in 1995 and two months of mild drought in 1997. There was one month of mild drought in 1996, the lowest exposure year.

The risk of foliar ozone injury to plants at Morristown National Historic Park is high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury developing in the higher exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels exceed the thresholds, and soil moisture levels are under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, American elder, and northern fox grape.

ROOSEVELT-VANDERBILT HEADQUARTERS (ROVA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ROVA					
	1995	1996	1997	1998	1999
Sum06	20	15	19	18	21
W126	25.9	21.8	24.7	28.4	29.7
N60	408	340	373	469	452
N80	97	66	89	92	114
N100	18	12	13	11	25

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ROVA					
	1995	1996	1997	1998	1999
Month 1	-3.26	1.08	-2.31	-1.72	-2.93
Month 2	-0.79	6.42	-0.42	-1.75	-2.40
Month 3	-2.62	-1.18	0.84	-2.05	-0.75

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ROVA					
	1995	1996	1997	1998	1999
April	-1.05	3.59	0.89	0.02	-3.01
May	-1.59	0.56	-0.23	1.03	-0.22
June	-3.26	1.08	-2.31	5.16	-2.93
July	-0.79	6.42	-0.42	-1.72	-2.40
August	-2.62	-1.18	0.84	-1.75	-0.75
September	-1.04	2.19	-0.39	-2.05	5.84
October	5.01	1.56	-1.26	0.04	0.73

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations:

when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The Sum06 indices of exposure were relatively similar over the five-year period, and the inverse relationship with soil moisture is not consistent. The two years with the highest ozone exposures, 1999 and 1995, both had two months of moderate and severe drought. The two next highest years, 1997 and 1998, respectively experienced one and three months of mild to moderate drought, while the year with the lowest ozone, 1996, has one month of mild drought. Annual ozone levels associated with the seasonal W126 index were similar in value, and also appear to be inversely related to soil moisture. The two highest ozone years, 1999 and 1998, each had three months of mild to severe drought. Two years with mid-level exposures, 1995 and 1997, had five and two months of mild to severe drought, respectively, and the year with lowest ozone, 1996, has one month of mild drought.

The risk of foliar ozone injury to plants at Roosevelt-Vanderbilt Headquarters is high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury developing in higher exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest in years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under drought conditions that do not extensively constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, and northern fox grape.

SAINT-GAUDENS NATIONAL HISTORIC SITE (SAGA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SAGA					
	1995	1996	1997	1998	1999
Sum06	7	5	7	7	9
W126	13.0	10.9	11.2	12.4	15.0
N60	198	134	149	183	221
N80	21	22	23	12	32
N100	1	1	3	1	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SAGA					
	1995	1996	1997	1998	1999
Month 1	-2.43	-1.03	-2.37	-0.70	-0.28
Month 2	0.51	4.24	0.24	8.48	-2.02
Month 3	-1.60	-3.39	1.24	-1.14	-1.13

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SAGA					
	1995	1996	1997	1998	1999
April	-1.75	4.73	2.08	-1.97	-4.13
May	-0.59	1.79	-0.30	-0.70	-0.28
June	-2.43	-1.03	-2.37	8.48	-2.02
July	0.51	4.24	0.24	-1.14	-1.13
August	-1.60	-3.39	1.24	-1.21	-1.16
September	-1.27	0.48	-1.38	-1.76	5.80
October	4.81	7.22	-2.06	0.91	1.32

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between both the 90-day Sum06 and the seasonal W126 indices of ozone exposure and soil moisture are difficult to assess because the levels of exposure for both were low and similar over the five-year period. There does not appear to be any association between the Sum06 levels of ozone exposure and the incidence of drought. Soil moisture levels show that each year had one or two months of mild to severe drought. The relatively uniform levels of ozone exposure for the W126 index also make it difficult to assess relationships between exposure and soil moisture. Months of mild, moderate, and severe drought stress were distributed throughout the five-year period with each year having two to four months of drought. No associations between the W126 levels of ozone and soil moisture are apparent in the distribution.

The low levels of ozone exposure at Saint-Gaudens National Historic Site make the risk of foliar ozone injury to plants low. The Sum06 and W126 exposures indices do not exceed the threshold levels for injury, the number of hours of exposure greater than 80 ppb is low, and exposure to concentrations greater than 100 ppb are rare. Months of mild to severe drought throughout the assessment period limit the uptake of ozone and serve to reduce the effectiveness of the ozone exposures.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, and American elder.

SARATOGA NATIONAL HISTORIC PARK (SARA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SARA					
	1995	1996	1997	1998	1999
Sum06	13	8	12	12	16
W126	18.1	14.5	17.4	18.0	23.5
N60	290	212	260	300	380
N80	44	31	39	24	62
N100	2	2	4	2	7

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SARA					
	1995	1996	1997	1998	1999
Month 1	-3.26	1.08	-2.31	1.03	-0.22
Month 2	-0.79	6.42	-0.42	5.16	-2.93
Month 3	-2.62	-1.18	0.84	-1.72	-2.40

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SARA					
	1995	1996	1997	1998	1999
April	-1.05	3.59	0.89	0.02	-3.01
May	-1.59	0.56	-0.23	1.03	-0.22
June	-3.26	1.08	-2.31	5.16	-2.93
July	-0.79	6.42	-0.42	-1.72	-2.40
August	-2.62	-1.18	0.84	-1.75	-0.75
September	-1.04	2.19	-0.39	-2.05	5.84
October	5.01	1.56	-1.26	0.04	0.73

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation, but often on a marginal basis. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 threshold was marginally satisfied while the W126 was not.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had seven hours in which the concentration exceeded 100 ppb, but most years had only two hours. These levels of exposure are not likely to injure vegetation.

- Although ozone exposure indices during the 90-day Sum06 accumulation periods were relatively similar, they appear to be inversely related to soil moisture levels: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest and second highest Sum06 ozone exposure values, 1999 and 1995, each had two months of

moderate to severe drought. Two years with slightly lower ozone exposure, 1997 and 1998, each had one month of mild or moderate drought. In the lowest ozone year, 1996, there was one month of mild drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, but the pattern is not consistent. The year with the highest exposure, 1999, had three months of moderate and severe drought. In the three mid-level exposure years, there were five months of mild to severe drought in 1995, three months of mild and moderate drought in 1998, and two months of mild and moderate drought in 1997. The lowest exposure year, 1996, experienced one month of mild drought.

The low levels of ozone exposure at Saratoga National Historic Park make the risk of foliar ozone injury to plants low. The Sum06 and W126 exposure indices marginally exceed and do not exceed, respectively, the threshold levels for injury. The number of hours of exposure greater than 80 ppb is low, and exposure to concentrations greater than 100 ppb are rare. Months of mild to severe drought throughout the assessment period serve to constrain the uptake of ozone and reduce the effectiveness of the exposures.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, white ash, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.

SAUGUS IRON WORKS NATIONAL HISTORIC SITE (SAIR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Prunus serotina	Black cherry	Rosaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SAIR					
	1995	1996	1997	1998	1999
Sum06	12	10	10	11	12
W126	20.6	16.6	19.3	19.8	19.0
N60	316	250	283	302	285
N80	83	38	65	60	69
N100	14	2	11	11	10

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SAIR					
	1995	1996	1997	1998	1999
Month 1	-0.41	-1.56	-1.75	6.79	-3.30
Month 2	-0.70	2.18	-1.04	-0.18	-0.73
Month 3	-2.61	-0.20	0.19	0.48	-1.85

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SAIR					
	1995	1996	1997	1998	1999
April	-1.80	1.88	2.21	0.31	-3.25
May	-0.46	-0.43	-0.23	0.90	0.13
June	-0.41	-1.56	-1.75	6.79	-3.30
July	-0.70	2.18	-1.04	-0.18	-0.73
August	-2.61	-0.20	0.19	0.48	-1.85
September	-0.80	5.52	-2.36	-1.29	2.54
October	1.54	8.00	-2.07	1.39	2.55

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index marginally exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. Ambient concentrations exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Ozone exposure values during the 90-day Sum06 and seasonal W126 accumulation periods were similar for each index over the five-year period of evaluation, and provide little opportunity to assess relationships between levels of exposure and soil moisture. For the Sum06 index, one and two months of mild, moderate, and severe drought were distributed over four of the five years without any apparent relationship to the level of ozone. The W126 index of exposure saw two to four months of mild to severe drought distributed in four of the five years, with one month of mild drought in 1996, the lowest ozone exposure year. No

relationship appears to exist between the W126 level of exposure and soil moisture conditions.

The risk of foliar ozone injury to plants at Saugus Iron Works National Historic Site is moderate. While the levels of ozone exposure create the potential for injury, dry soil conditions significantly reduce the likelihood of injury in some years. However, levels of exposure capable of producing foliar injury also occur under conditions of minor drought. The probability of foliar injury developing may be greatest during years such as 1998 when ozone levels exceed the thresholds, and soil moisture levels do not serve as a long-term constraint to the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, black cherry, and northern fox grape.

WEIR FARM NATIONAL HISTORIC SITE (WEFA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for WEFA					
	1995	1996	1997	1998	1999
Sum06	18	13	19	17	23
W126	23.6	19.2	24.3	27.3	28.4
N60	351	295	347	432	418
N80	110	70	114	109	128
N100	29	14	31	17	38

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WEFA					
	1995	1996	1997	1998	1999
Month 1	-2.05	-0.91	-1.80	3.97	-3.65
Month 2	-1.45	3.27	-0.82	0.19	-1.80
Month 3	-1.82	-1.27	2.01	-1.52	-1.74

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at WEFA					
	1995	1996	1997	1998	1999
April	-1.37	3.37	0.37	0.04	-3.16
May	-0.75	-0.44	-0.44	1.42	-0.36
June	-2.05	-0.91	-1.80	3.97	-3.65
July	-1.45	3.27	-0.82	0.19	-1.80
August	-1.82	-1.27	2.01	-1.52	-1.74
September	-0.53	1.98	-2.07	-1.55	4.99
October	4.44	3.89	-1.68	1.47	1.71

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period indices of ozone exposure appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1999, had three months of mild and severe drought while the year with the second highest exposure, 1997, had one month of mild drought. The two years with mid-level exposures, 1995 and 1998,

experienced three months of mild and moderate drought and one month of mild drought, respectively. There was one month of mild drought in 1996, the lowest exposure year. The W126 level of ozone exposure also appears to be an inversely related to soil moisture, although the pattern is not consistent. In 1999 when the exposure was the greatest, there were four months of mild and severe drought. There were two months of mild drought in 1998, the year with the second highest exposure. The two years with mid-level exposures, 1997 and 1995, experienced three and four months of mild and moderate drought, respectively. There was one month of mild drought in 1996, the lowest exposure year.

The risk of foliar ozone injury to plants at Weir Farm National Historic Site is high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury in high exposure years. Levels of exposure capable of producing foliar injury also occur under conditions of minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1996 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, white ash, yellow-poplar, quaking aspen, black cherry, Allegheny blackberry, American elder, and northern fox grape.